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DRAINAGE NETWORK ANALYSIS OF A SUBARCTIC WATERSHED. CARIBOU-POK--ETC(U)
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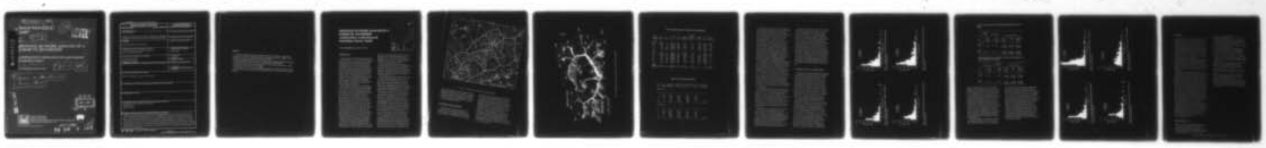

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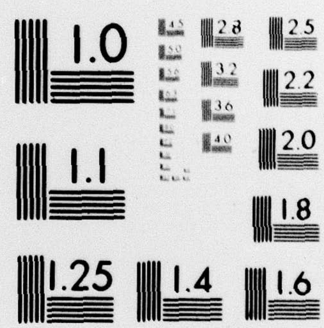

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Special Report 79-19

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DRAINAGE NETWORK ANALYSIS OF A SUBARCTIC WATERSHED

CARIBOU-POKER CREEKS RESEARCH WATERSHED, INTERIOR ALASKA

(9) Special rept.

S.R. Bredthauer and D. Hoch

(10) Steven R. /Bredthauer
David /Hoch

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CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

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79 09 4 103

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Special Report 79-19

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
A038447 A068682
DRAINAGE NETWORK ANALYSIS OF A SUBARCTIC WATERSHED: CARIBOU-POKER CREEKS RESEARCH WATERSHED, INTERIOR ALASKA

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Stephen R. Bredthauer and David Hoch

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
CWIS 31003

11. CONTROLLING OFFICE NAME AND ADDRESS
Directorate of Civil Works
Office, Chief of Engineers
Washington, D.C. 20314

12. REPORT DATE
June 1979

13. NUMBER OF PAGES
11

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Caribou-Poker Creeks Watershed, Interior Alaska
Drainage network
Statistical analysis

59 Km

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A Strahler stream order analysis and an exterior link length distribution analysis were made of the Caribou-Poker Creeks Research Watershed, near Fairbanks, Alaska. The drainage network map used for analysis was produced using a 1:2250 scale aerial photograph mosaic. Low drainage densities, ranging from 1.35 km/km^2 to 5.34 km/km^2, characterize the basins. Bifurcation ratios indicate that the overall drainage network is not dominated by strong geologic controls. Statistical analysis indicates that bifurcating source links and tributary source links do not belong to the same length population, a characteristic shared by watersheds in other climatic regions of the world. Additional analysis indicates that exterior links originating on permafrost slopes tend to be shorter than those originating on non-permafrost, well-drained slopes.

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PREFACE

This report was prepared by Stephen R. Bredthauer, Research Civil Engineer, of the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), and by David Hoch, Geologist, University of Alaska, Fairbanks, Alaska.

The study was funded under DA Program, *Flood Control and Navigation;* Subprogram, *Hydrology of Cold Regions;* and Work Unit CWIS 31003, *Watershed Studies in Cold Regions.*

Technical review of this report was performed by Dr. P. Jan Cannon of the University of Alaska, Fairbanks, and by Dr. Daniel E. Lawson of CRREL.

Special thanks are given to Dr. Charles Slaughter and Eugene Culp, Institute of Northern Forestry, U.S. Forestry Service, who compiled the aerial photograph mosaic of Caribou-Poker Creek Research Watershed.

DRAINAGE NETWORK ANALYSIS OF A SUBARCTIC WATERSHED
Caribou-Poker Creeks Research Watershed, Interior Alaska

S.R. Bredthauer and D. Hoch

INTRODUCTION

The Caribou-Poker Creeks Research Watershed was established in 1969 as a site for long-term investigation of the taiga environment. Research is initially aimed toward developing an understanding of hydrologic, climatologic and environmental relationships in an undisturbed setting of the Yukon-Tanana Uplands of the Northern Plateaus Physiographic Province, Central Alaska. The general location and the major sub-basins of the Caribou-Poker Creeks Rsearch Watershed are shown in Figure 1. Sub-basins labeled C-1, C-2, etc., are those in the Caribou Creek Watershed, while those labeled P-1, P-2, etc., are sub-basins in the Poker Creek Watershed. The sub-basins are delineated by their watershed boundaries and are arbitrarily numbered for identification purposes.

The watersheds are underlain by frost-shattered Precambrian Birch Creek schists (Koutz and Slaughter 1972). This area is characterized by rounded, steep-sided ridges, with narrow, V-shaped headwater valleys. It is mantled by a thin cap of loess but, because the loess is derived from the floodplains of streams draining areas of the same formation, there is no sharp boundary between it and the weathered schist below it (Rieger et al. 1972). The soils are poorly drained and underlain by permafrost on north-facing slopes and in valley bottoms, and free from permafrost on south-facing slopes. The vegetation consists of black spruce/larch/alder with a thick moss, lichen, and shrub understory on north-facing slopes. An aspen/birch/alder complex covers south-facing slopes with isolated stands of mature white spruce and small areas of alpine tundra present. Valley bottoms are dominated by poorly drained riparian communities of willows, dwarf birch, cottongrass, and blueberry.

The climate of the region is continental subarctic with short, warm summers and long, cold winters. January, typically the coldest month, has a mean minimum temperature of -28°C, whereas July, the warmest month, has a mean maximum temperature of 24.5°C (Slaughter 1971). Annual precipitation generally ranges from 25 cm to 38 cm, over half of which falls during June, July, and August. Snowfall averages 125 cm to 150 cm per year (Ford 1973).

Quantitative geomorphic parameters were calculated to provide a description of watershed geometry and to provide a basis for comparison with other watersheds. A Strahler stream order analysis (Strahler 1964) was conducted to quantify the lengths of the component streams and to determine the number of streams within each order.

The exterior link of a channel network is the same as Strahler's first-order stream. For this study, exterior links were further divided into two subsets: bifurcating source links and tributary source links (Mock 1971). Bifurcating source links merge with links of equal magnitude, while tributary source links merge with links of higher magnitude. The population distributions of link lengths play an important role in the statistical properties of the entire stream network and play a primary role in the development of channel network simulation models. The length distributions of bifurcating source and tributary source links in Caribou Creek and Poker Creek were analyzed statistically to see if patterns observed in other geographic areas were also observed in these subarctic basins. The source links were then divided into those links originating on permafrost and those not originating on permafrost. A statistical analysis was then conducted on the length distribution of these two subsets in order to gain some insight into the effect of permafrost on the channel network.

The drainage network map (Fig. 2) used in this study was constructed from a 1:2250 scale aerial photograph mosaic. Stream channels were identified and drawn with the aid of a magnifying stereoscope. Some bias is inherent in this type of mapping process, but it was felt that the need for detail greater than that provided by the standard 1:63360 scale USGS

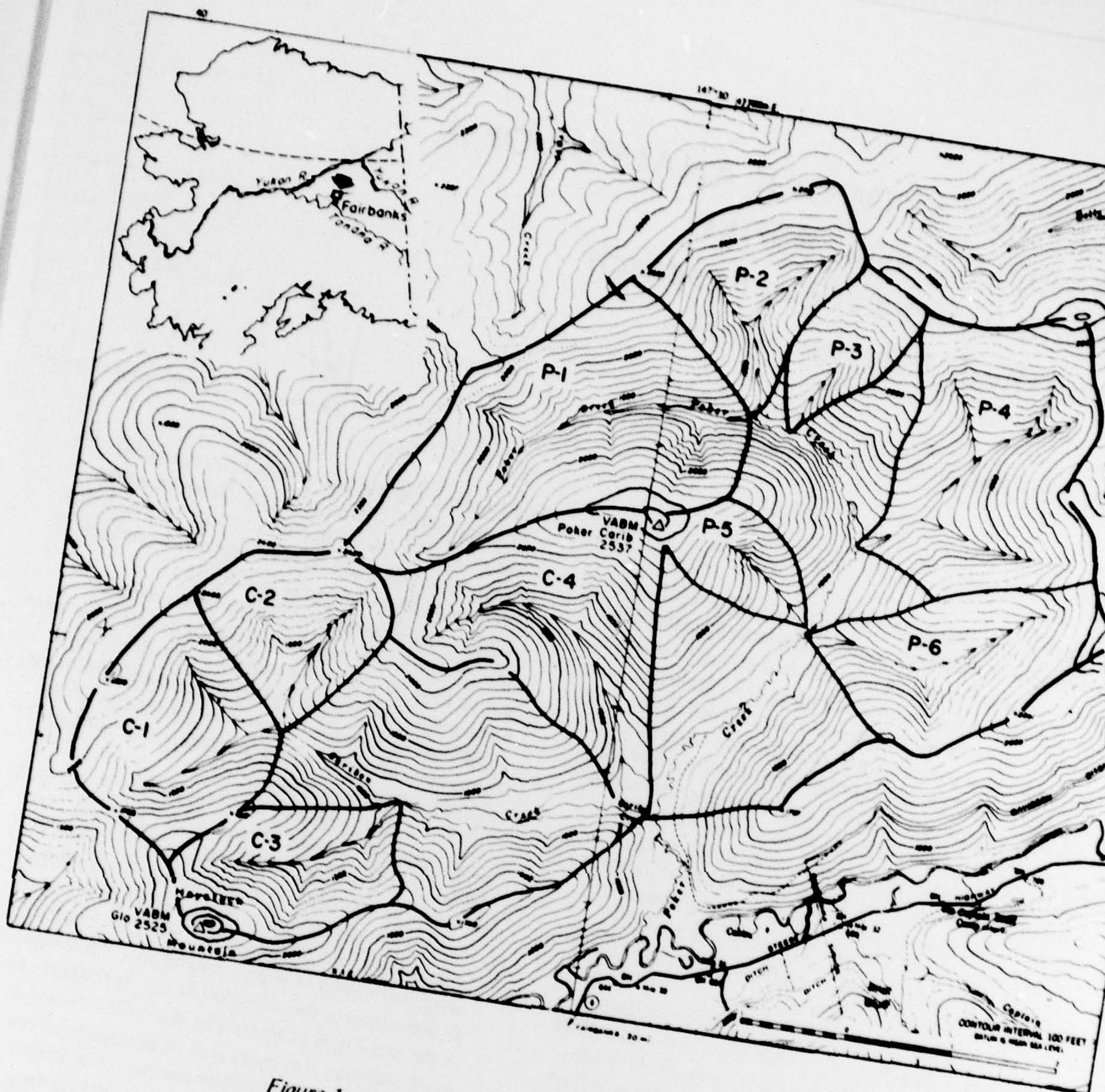

Figure 1. Contour map, Caribou-Poker Creeks Watershed.

quadrangle justified the use of this method. Stream lengths and drainage areas were measured on a digitizer; a peripheral computer performed all calculations and plotted the histograms. The shaded areas of the map are underlain by permafrost, derived from a soils map of the basin (Rieger et al. 1972).

WATERSHED CHARACTERISTICS

Various physical hydrologic characteristics of Caribou-Poker Creeks Research Watershed are summarized in Table 1. Geographic areas were defined by watershed boundaries delineated on the drainage network map (Fig. 2). Permafrost underlies 28.0% of the Caribou Creek Basin and 30.5% of the Poker Creek Basin. Total relief, the elevation difference between the highest and the lowest point in a specified geographic area, ranges from a minimum of 404 m in sub-basin C-1 (Fig. 1) to a maximum of 597 m in the Poker Creek Basin. Total stream lengths for Caribou and Poker Creeks are 121.8 km and 199.9 km, respectively. The drainage density, an expression of the closeness of spacing of channels (Strahler 1964), is defined as the total stream length divided by the basin area. Values for the sub-basins defined on the drainage network map (Fig. 2) ranged from 1.35 km/km^2 to 5.34 km/km^2, with an overall density of 3.36 km/km^2 for the entire watershed.

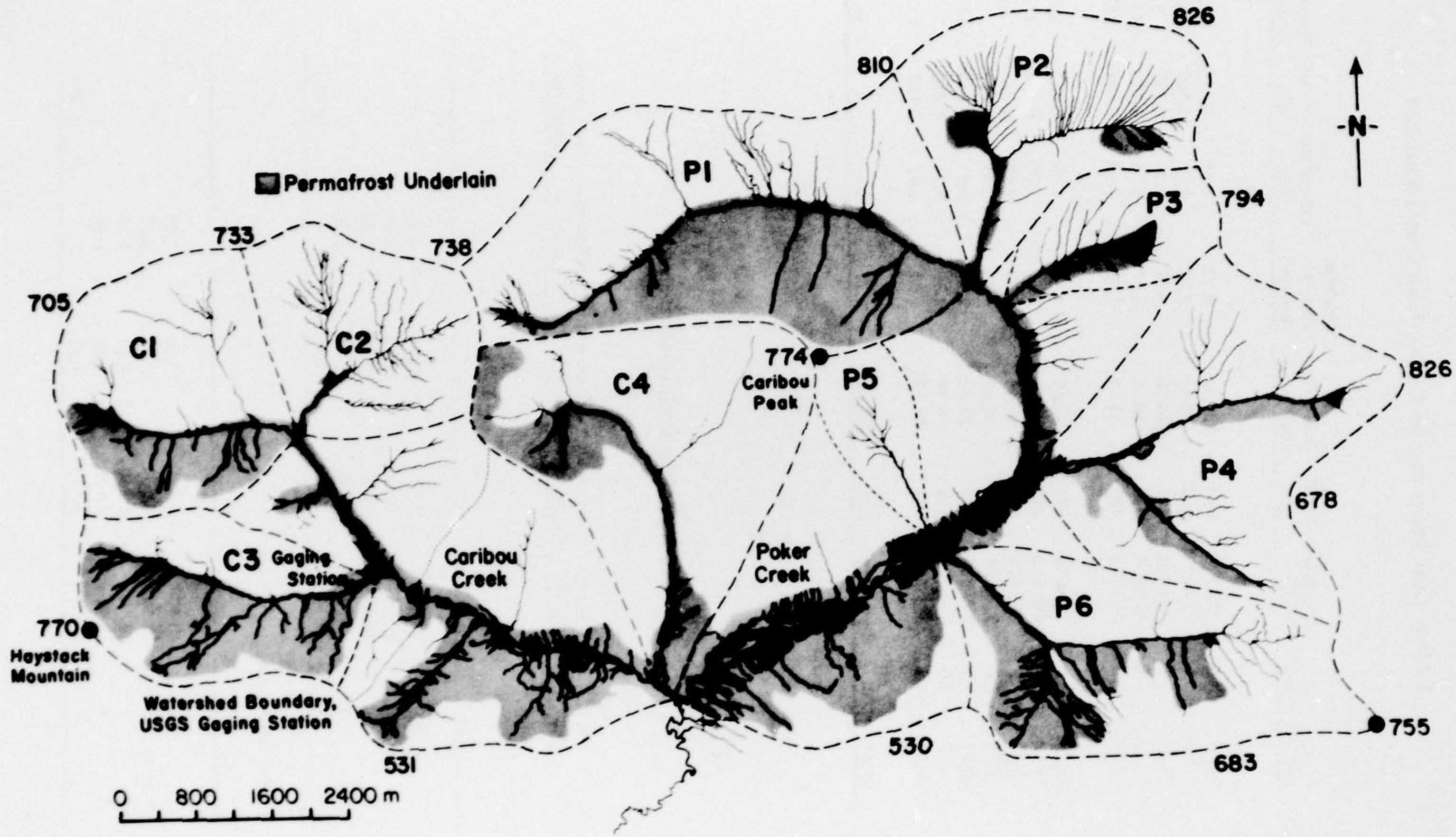

Figure 2. Drainage network map, Caribou-Poker Creeks Research Watershed.

Table 1. Quantitative data for Caribou-Poker Creeks Watershed.

Basins/ Sub-basins	*Area (km^2)*	*Aspect*	*Elev. range (m)*	*Relief (m)*	*Total stream length (km)*	*Drainage density (km/km^2)*	*Elongation ratio*	*Relief ratio*	*Percent Permafrost*
Caribou									
Main	38.87	E	229-773	544	121.75	3.13	0.68	0.052	28.0
C-1	6.68	E	329-733	404	18.17	2.72	1.20	0.165	26.1
C-2	5.21	S	329-738	409	24.58	4.72	0.97	0.155	3.5
C-3	5.54	NE	305-770	465	20.79	3.57	0.76	0.133	53.2
C-4	9.72	SSE	240-773	533	13.13	1.35	0.69	0.104	18.8
Poker									
Main	56.60	S	229-826	597	199.89	3.53	1.73	0.049	30.5
P-1	13.09	ENE	358-810	452	34.99	2.67	1.09	0.092	37.8
P-2	6.83	S	358-826	468	36.46	5.34	0.79	0.125	6.9
P-3	2.70	SW	320-794	474	10.87	4.03	0.91	0.232	
P-4	10.07	SW	299-826	527	23.83	2.37	0.97	0.143	14.2
P-5	1.73	SE	274-774	500	4.94	2.86	0.74	0.248	
P-6	8.38	NW	273-755	482	27.70	3.31	0.87	0.128	17.8
Caribou-Poker	95.47	----	229-826	597	321.64	3.37	----	----	30.7

Table 2. Strahler stream order analysis.

Stream order	*No. of streams*	*Total stream length (km)*	*Mean stream length (km)*	*Percent of total length*	*bifurcation ratio*	*Main channel length (km)*
Caribou Creek						
1	289	73.43	0.254	60.31	4.52	
2	64	23.06	0.360	18.94	6.40	
3	10	14.61	1.461	12.00	3.33	
4	3	3.51	0.509	2.88	3.00	
5	1	7.14	7.140	5.86		10.03
Poker Creek						
1	489	140.49	0.287	70.28	4.89	
2	100	26.43	0.264	13.22	6.25	
3	16	16.16	1.010	8.08	3.20	
4	5	7.68	1.536	3.84	5.00	
5	1	9.13	9.130	4.57		15.97

The relief ratio, a measure of the overall steepness of a drainage basin and an indicator of the intensity of erosion processes operating on slopes of the basin (Strahler 1964), was defined by Schumm (1956, p. 612) as "The ratio between the total relief of a basin and the longest dimension of the basin parallel to the principal drainage line." However, the divisor in this definition is not explicit, and it is difficult for two investigators to obtain the same length for an identical drainage basin. Recognizing this, Cannon (1976) tested various explicit length parameters for the divisor and concluded the relief ratio calculated with the cumulative total of mean stream length is closely related to the entire drainage basin and perhaps better reflects the hydrogeologic regimen of the drainage basin under consideration. Using Cannon's definition, the relief ratios for Caribou Creek and Poker Creek are 0.052 and 0.049, respectively.

The elongation ratio, an indicator of basin geometry, may be related to the stream's adjustment to structure and to the geologic history of the basin (Cannon 1976, p. 10). As defined by Schumm (1956, p. 612), the elongation ratio is the ratio of the diameter of a circle having the same area as the basin to the longest dimension of the basin parallel to the principal drainage line. The divisor in the elongation ratio is also subject to misinterpretation. Cannon (1976) tested various explicit length parameters, and determined that the cumulative total of mean stream length would best relate the elongation ratio to the entire drainage net of the basin. Using Cannon's definition, the elongation ratios for Caribou Creek and Poker Creek are 0.68 and 1.73, respectively.

A Strahler stream order analysis was conducted for Caribou and Poker Creeks, using the drainage network map (Fig. 2). Using an aerial photograph mosaic, an attempt was made to include all intermittent and permanent streams within the watershed in the drainage network map. Following the system presented by Strahler (1957, p. 914), each source tributary is designated Order 1. Where two first-order channels join, a second-order segment is formed; where two second-order channels join, a third-order segment is formed; etc. (Fig. 2).

Using Strahler's stream ordering system, the bifurcation ratio was determined. Bifurcation ratio is defined as the ratio of the number of streams of order n to the number of streams of next highest order ($n + 1$). The number is highly stable, characteristically ranging from 3.0 to 5.0 in watersheds where powerful geologic controls do not dominate (Strahler 1964). Except for the bifurcation ratio of second- to third-order streams, the bifurcation ratios for Caribou and Poker Creeks fell within this range (Table 2).

Distribution of channel lengths was also determined using the Strahler stream order analysis. First-order streams constitute 60.3% of total stream length in Caribou Creek and 70.3% of total stream length in Poker Creek. Main channel length for Caribou and Poker Creeks was explicitly defined using the method of Cannon (1976). The main channel length was found by adding the length of the highest order stream to the longer of the two next lower-order streams forming the main stream. The above process was continued through the first-order streams. For example, the length of the fifth-order stream in Caribou Creek was added to the longer of the two fourth-order streams composing it. The fourth-order stream was followed until it reached the point where it was formed by two third-order streams merging. The longer of these two was added to the main channel length, and the process was repeated for second- and first-order streams. The value found by this method is believed to be representative.

EXTERIOR LINK LENGTH DISTRIBUTIONS

As previously mentioned, the population distributions of link lengths play an important role in the statistical properties of the entire drainage network. Exterior links have been subdivided into two subsets, bifurcating source links and tributary source links, each occupying a different space in relation to the entire drainage network. Absolute frequency distributions and the mean ($\bar{x}$) and variance (s^2) of bifurcating source and tributary source link lengths for Caribou and Poker Creeks are shown in Figures 3-6. A statistical analysis was conducted to determine if these two distinct subsets of exterior links have the same length distribution, or if they would have to be treated separately in a channel network simulation model.

Following Abrahams and Campbell (1976), the null hypothesis that bifurcating source links and tributary source links have the same length distribution was treated for both Caribou Creek and Poker Creek by the following three nonparametric statistical methods (Siegel 1956): (1) the contingency table χ^2 test for two independent samples, (2) the median test, and (3) the Kolmogorov-Smirnov two-sample test. All three tests were used because each examines a different property of the sample distributions. The χ^2 test determines the significance of differences between two independent groups in which the data consist of frequencies in discrete categories. The median test determines whether two independent groups differ in central categories. The Kolmogorov-Smirnov two-sample test determines whether two in-

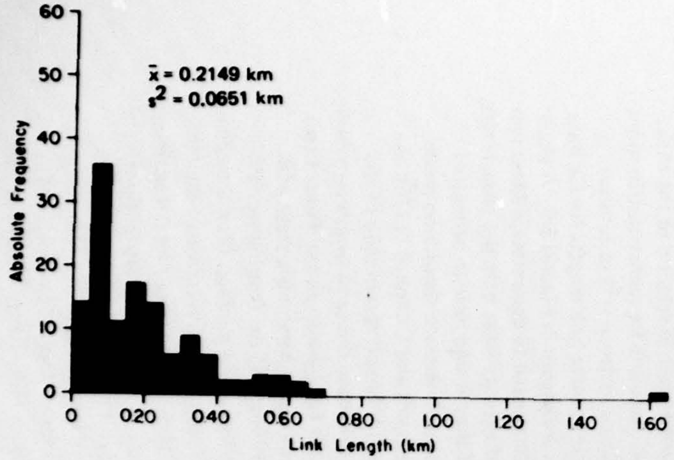

Figure 3. Absolute frequency distribution, lengths of bifurcating source links, Caribou Creek.

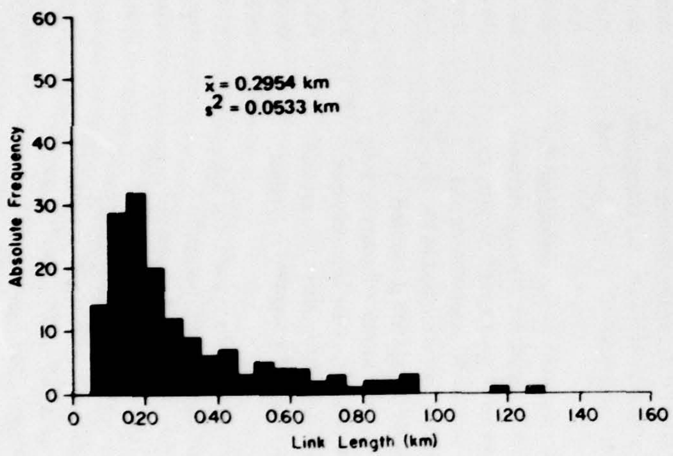

Figure 4. Absolute frequency distribution, lengths of tributary source links, Caribou Creek.

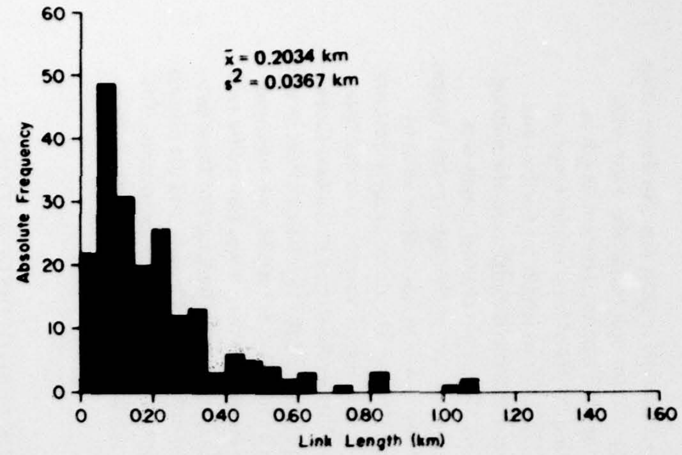

Figure 5. Absolute frequency distribution, lengths of bifurcating source links, Poker Creek.

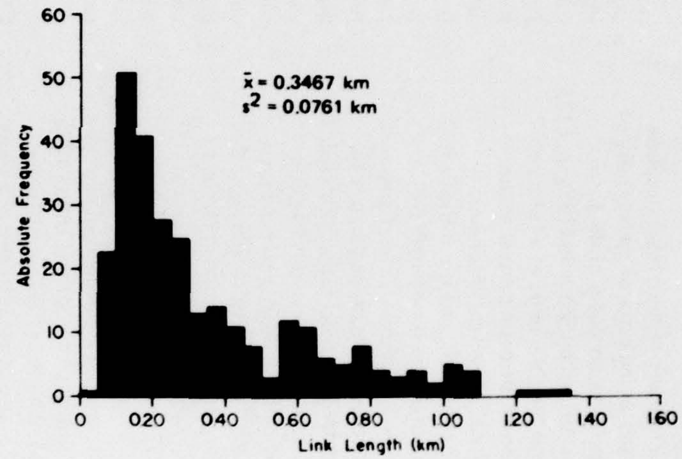

Figure 6. Absolute frequency distribution, lengths of tributary source links, Poker Creek.

Table 3. Statistical tests comparing bifurcating and tributary source link lengths.

	Bifurcating Source links		*Tributary-source links*		*Decision (α = 0.05)*		
Basin	No.	Mean length (km)	No.	Mean length (km)	χ^2 Contin-gency table	Median test	Kolmogorov-Smirnov test
Caribou Creek	125	0.215	160	0.295	Rejected $P<0.001$	Rejected $P<0.01$	Rejected $P<0.001$
Poker Creek	203	0.203	285	0.347	Rejected $P<0.001$	Rejected $P<0.001$	Rejected $P<0.001$

Table 4. Statistical tests comparing permafrost exterior links lengths and nonpermafrost exterior link lengths.

	Permafrost links		*Nonpermafrost links*		*Decision (α = 0.05)*		
Basin	No.	Mean length (km)	No.	Mean length (km)	χ^2 Contin-gency table	Median test	Kolmogorov-Smirnov test
Caribou Creek	164	0.229	125	0.287	Rejected $P<0.025$	Rejected $P<0.025$	Rejected $P<0.01$
Poker Creek	278	0.188	211	0.418	Rejected $P<0.001$	Rejected $P<0.001$	Rejected $P<0.001$

dependent samples have been drawn from the same population, and is sensitive to any kind of difference in distributions from which the two samples are drawn. If the null hypothesis were rejected by just one test at the $\alpha = 0.05$ probability level, the samples could be concluded to belong to different populations. Results of the three tests are shown in Table 3. The null hypothesis that the samples of bifurcating source and tributary source link lengths were drawn from the same population is rejected at or below the 0.01 probability level ($P < 0.01$) for both basins by all three tests, with most rejections at the 0.001 level ($P<0.001$). Therefore, it can be concluded that, in the subarctic watersheds analyzed, bifurcating source and tributary source links belong to different length-populations. source and tributary source links belong to different length-populations.

To gain some insight into the effect of permafrost on the length distribution of exterior links, the exterior links were subdivided into those originating in areas underlain by permafrost and those originating in areas with no permafrost. The absolute frequency distributions of these two subsets are shown in Figures 7-10. The null hypothesis that exterior links originating in areas underlain by permafrost have the same length distribution as exterior links originating in areas with no permafrost was tested using the three nonparametric statistical methods previously used: (1) the contingency table χ^2 test for two independent samples, (2) the median test, and (3) the Kolmogorov-Smirnov two-sample test. The results of the tests are shown in Table 4. The null hypothesis was rejected at or below the 0.025 ($P < 0.025$) level for Caribou Creek and at the 0.001 ($P < 0.001$) level for Poker Creek. It can be concluded that, within the Caribou-Poker Creek Watershed, links originating in areas underlain by permafrost tend to be shorter than those originating in areas with no permafrost.

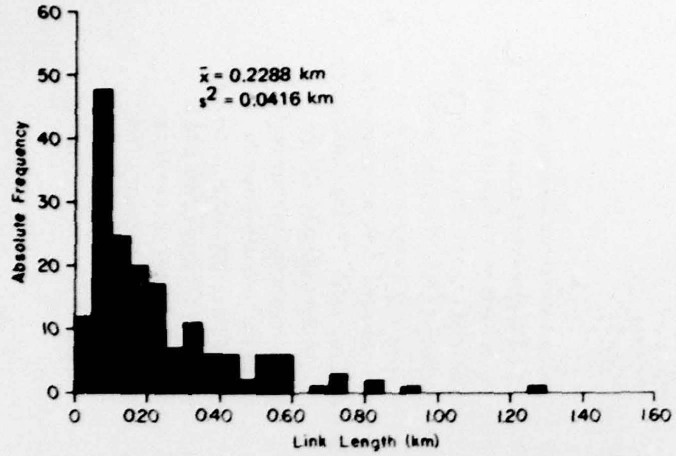

Figure 7. Absolute frequency distribution, lengths of permafrost exterior links, Caribou Creek.

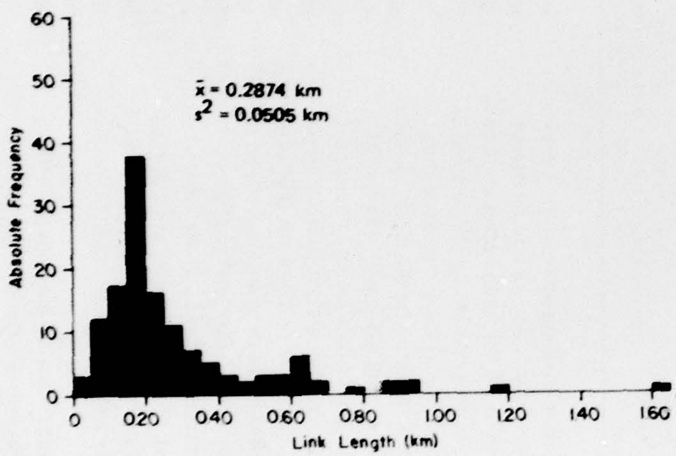

Figure 8. Absolute frequency distribution, lengths of nonpermafrost exterior links, Caribou Creek.

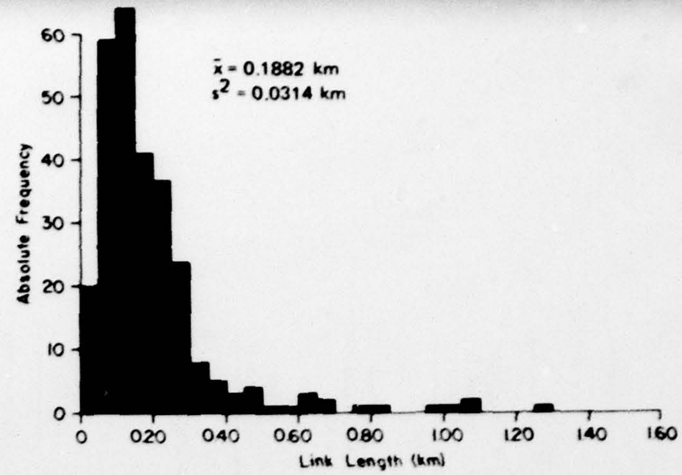

Figure 9. Absolute frequency distribution, lengths of permafrost exterior links, Poker Creek.

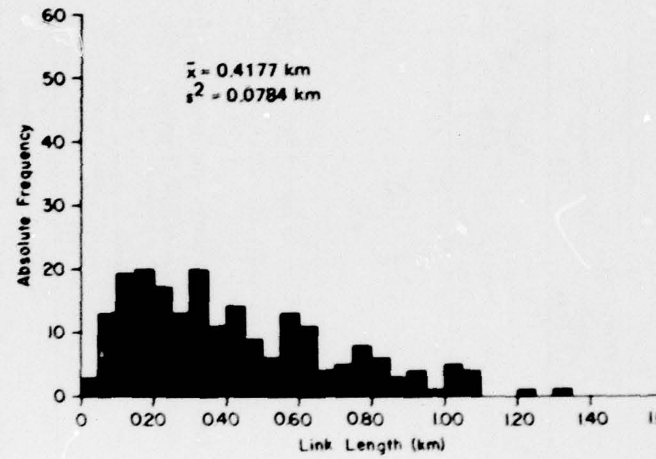

Figure 10. Absolute frequency distribution, lengths of nonpermafrost exterior links, Poker Creek.

DISCUSSION

Drainage densities within the Caribou-Poker Creeks Watershed are in the coarse range (less than 5.00) as defined by Strahler (1957). Coarse values are common in areas of permeable rocks and of low rainfall intensities (Gregory and Walling 1973, p. 47). Ground cover in the watershed is primarily either forest litter, or the highly permeable moss that overlies permafrost areas. Rainfall intensities in the region are very light (Santeford 1976, p. 18). The low values of drainage density are therefore to be expected, considering the ground cover and rainfall intensities.

The bifurcation ratios of the Caribou-Poker Creeks Watershed indicate that strong geologic controls are not dominant. Strahler (1957) states that the bifurcation ratio is highly stable and shows only a small range (between 3-5) from region to region or from environment to environment, except where geologic controls dominate.

Statistical analysis of the frequency distributions of the lengths of bifurcation source and tributary source links indicated that tributary source links tend to be longer than bifurcating source links in this watershed. The two types of source links would have to be treated separately in a channel network simulation model. Similar results were noted by Abrahams and Campbell (1976) for six dissimilar watersheds in eastern Australia. The differences in length distributions are attributed to a tendency for the length of tributary-source links to increase downstream as the length of the main valley slopes on which they developed increased. This tendency was evident in the sub-basins of Caribou-Poker Creeks, but did not seem to apply to the lower basins, where a large number of short tributary-source links entered the drainage network as a result of subsurface flow exfiltrating near the base of the slopes.

Additional statistical analysis indicated that in this watershed exterior links originating on permafrost slopes tend to be shorter than exterior links originating on nonpermafrost slopes. Many of the exterior links originating on permafrost are the result of subsurface flow exfiltrating near the base of the slopes. As a result, these exterior links do not have far to travel to reach a higher-order stream.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1979 — 601-609/109